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CR # 152153

EXECUTIVE SUMMARY

A STUDY OF  
CHARACTERISTICS OF INTERCITY  
TRANSPORTATION SYSTEMS

PHASE I: DEFINITION OF  
TRANSPORTATION COMPARISON METHODOLOGY

by

J. Morley English  
Jeffrey L. Smith  
Melvin W. Lifson

prepared for

NASA-Ames Research Center  
and  
U. S. Department of Transportation

NASA Contract No. NAS2-9814

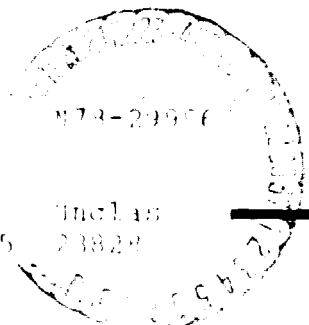
Econergy Report No. 12-801

ECONERGY, INC.

11777 San Vicente Boulevard, Suite 907  
Los Angeles, California 90049

August, 1978

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## EXECUTIVE SUMMARY

### 1. INTRODUCTION

#### 1.1 Objectives

The objectives of the ECONERGY study are:

- to develop a unified methodological framework for the comparison of intercity passenger and freight transportation systems
- to review the attributes of existing and future transportation systems for the purpose of establishing measures of comparison.

These objectives have been achieved and, in addition, were made more specific to include:

- development of a methodology for comparing long-term transportation trends arising from implementation of various R&D programs
- definition of value functions and attribute weightings needed needed for comparing alternative policy actions for furthering transportation goals.

It was not an objective of the Phase I study to implement the methodology beyond an illustrative example. While as much realism as possible and actual data where readily available, were utilized, the conclusions concerning transportation alternatives are, nevertheless, only illustrative.

#### 1.2 Reasons for Innovation in Evaluation of New Transportation Systems

Economic and social trends over the next 30 years will create pressures for changing the nation's transportation system in significant ways. Decision-making at the national level must be responsive to complex value systems representing transportation, environmental, societal, and economic policies and objectives.

Unfortunately, current planning technology has neither the analysis

models nor the data base for adequately dealing with:

- the complexity of intercity transportation systems
- the complexity of the interactions between a transportation system and the environments in which it is embedded.
- definition and application of the complex value systems that underlie transportation decision-making
- a long-term planning horizon.

Stated national policies emphasize "the protection and enhancement of the natural and human environment, the need for coordinating transportation improvement projects with related social, economic and environmental programs, and the desirability of fostering an open, informed and participatory decision-making process. The national policies have been articulated in such Federal legislation as the Department of Transportation Act of 1966 which requires:

'...the development of national transportation policies and programs conducive to the provision of fast, safe, efficient, and convenient transportation at the lowest cost consistent therewith and with other national objectives, including the efficient utilization and conservation of the Nation's resources.'

the Federal-Aid Act of 1970 which requires:

'...that possible adverse economic, social and environmental effects relating to any proposed project on any Federal-Aid system have been fully considered in developing such projects and that the final decisions on the project are made in the best overall public interest, taking into consideration the need for fast, safe and efficient transportation, public services, and the costs of eliminating or minimizing such adverse effects.'

and the National Environmental Policy Act of 1969, which requires:

'...a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision-making which may have



an impact on man's environment.'"

Furthermore, attention is becoming increasingly focused on the initial activities of the system acquisition process, on demonstrating that a choice of transportation concept or technology will achieve stated objectives, and on generally satisfying the information requirements of major decision milestones in the planning and development of major systems.

### 1.3 Features of Methodology

#### 1. Oriented to Decision Making

The primary purpose underlying comparison of intercity transportation systems is to provide information for decision-making in transportation planning, design, and management.

Therefore:

- it is desirable to be able to review, discuss and communicate the bases for major decisions.
- evaluation of alternatives should be consistent.
- evaluation of alternatives should be compatible with stated policies and objectives.

#### 2. Transportation Performance Evaluated in Terms of Economic and Social Values:

- relative worth functions are determined for a number of performance criteria
- weighting values are assigned
- relative worths over time are incorporated by means of discounting

#### 3. Introducing the Aspiration Concept:

- new transportation systems are evaluated over very long-run planning periods

- an aspiration for the long-term kind of transportation system which is presently deemed desirable is established

#### 4. Provides Justification for R&D Funding:

- in order to achieve the aspired transportation system of the long-run future, various technological developes will be needed; R&D programs will have to be initiated
- the timing for R&D decisions will be established by lead-times required for introducing new technologies

#### 5. Responsive to Agency Goals

OMB Circular A-109 states that federal agencies, when acquiring major systems:

- will express needs and program objectives in mission terms and not in equipment terms
- will place emphasis on the initial activities of the system acquisition process to allow competitive exploration of alternative system design concepts in response to mission needs
- should ensure appropriate trade-offs among investment costs, ownership costs, schedules and performance characteristics.

#### 1.4 Definitions

Because of possible semantic confusion, certain words are defined in the ECONERGY methodology. These words are often used in different contexts in other studies.

- **Mode:** a means of transportation -- aircraft, tracked-vehicle, automobile, buses, trucks, etc.
- **System:** the set of modes providing transportation in the specified intercity region; a system is not a network comprised of linkages of a parti-

cular mode as, for example, an airline route network

- **Alternative:** a particular mix of modes comprising a system; a particular system design as, for example, air, automobile, bus, rail, etc.
- **Aspiration:** the long term desired features for the transportation system

## 2. THE ECONERGY APPROACH

### 2.1 The Decision Situation

The primary objective of the Phase I Study was "to develop a unified framework for the comparison of intercity passenger and freight transportation systems." The Study was "to establish a consistent, uniform framework whereby any set of modal transportation systems may be evaluated in the context of a defined decision situation".

The decision for which the methodology has been particularized involves:

1. A long-range planning period - 50 years is considered appropriate to include planning, design and development, construction and operation of an intercity transportation system.
2. A broad geographic region - a region comprised of an intercity corridor, urban centers, and a non-urban, non-corridor area.
3. Consideration of significant social and economic (including demographic and environmental) effects.
4. Identification of future needs, expressed not only in terms of travel demands but also in terms of housing, recreation, and other community quality objectives. A key element of the methodology is the specifying of aspiration levels for both transportation and societal factors and using these aspirations as explicit guidelines for the transportation planning and design activities.
5. Evaluation of a multi-mode system as opposed to a single-mode evaluation. The alternative systems include most or all modes but with varied modal splits.
6. Identification of long-term transportation investment and improvement priorities and implementation schedules that

reflect those priorities.

The decision that the comparison methodology is designed to support is:

The selection of the "best" intercity modal transportation concept for support by the Federal government, where support may be either through direct financial aid *or through R&D funding of promising technologies.*

The evaluation framework is designed for decision-makers in agencies of the Executive Branch of the Federal government.

## 2.2 Methodological Framework

Every decision involves, either explicitly or implicitly, the activities indicated in Figure 1 (Figure 2.1 of the report).

## 2.3 Comparison Framework

Management has no choice as to whether the activities identified in Figure 2 (Figure 2.2 of the report) will be performed in a given decision situation. One way or another, synthesis, analysis and evaluation will be performed, in that sequence, in order to generate the information on which the decision is based.

Management does, however, have options concerning:

- (1) the type of information to be explicitly generated
- (2) the models to be used for analysis and evaluation
- (3) the sources of needed data
- (4) the physical, financial and personnel resources to be assigned to synthesis, analysis and evaluation
- (5) the timing of the development of the synthesis, analysis and evaluation capabilities

The decision-oriented problem-solving methodology depicted in Figure 2

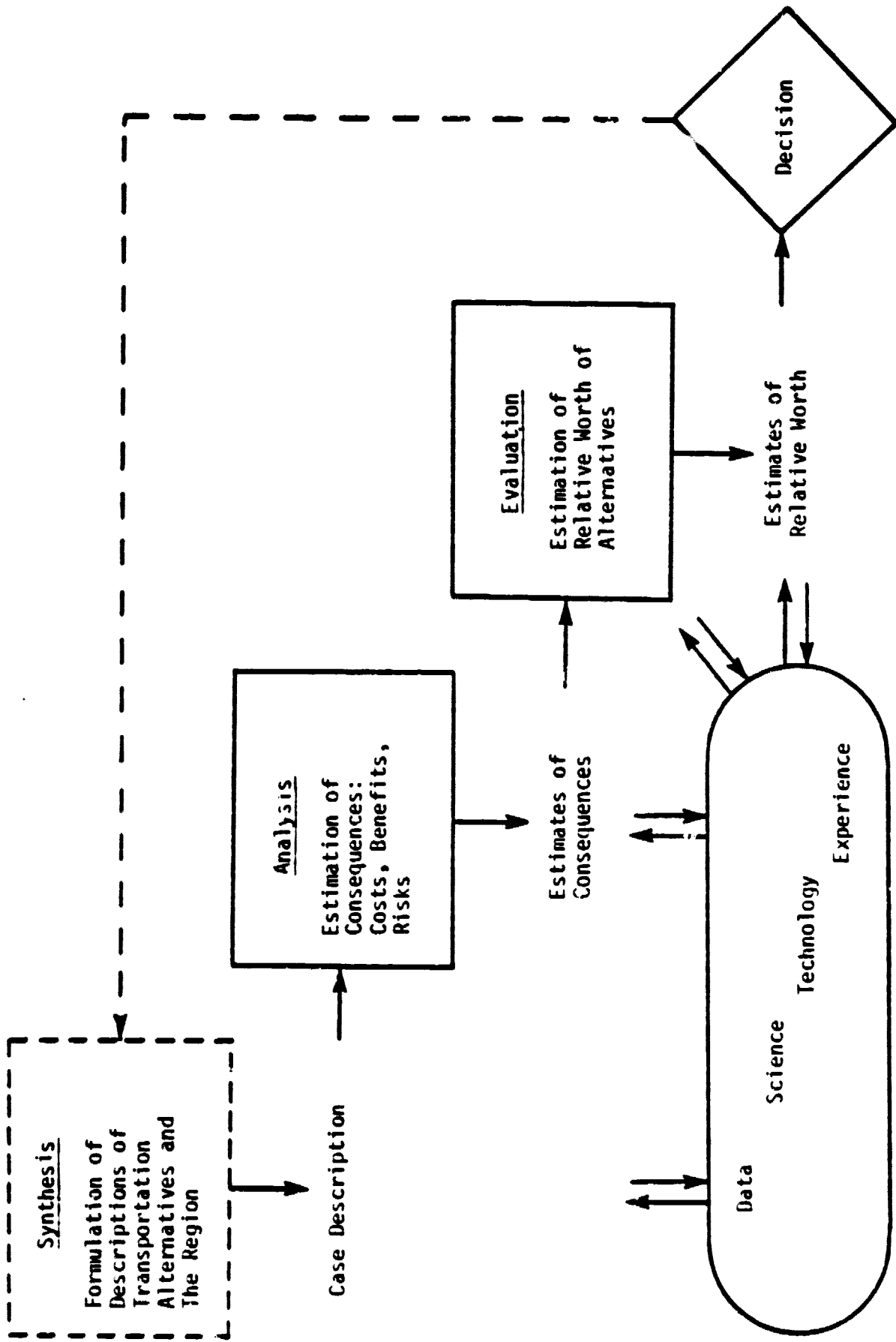


Figure 1 - Information Processing for Decision-Making

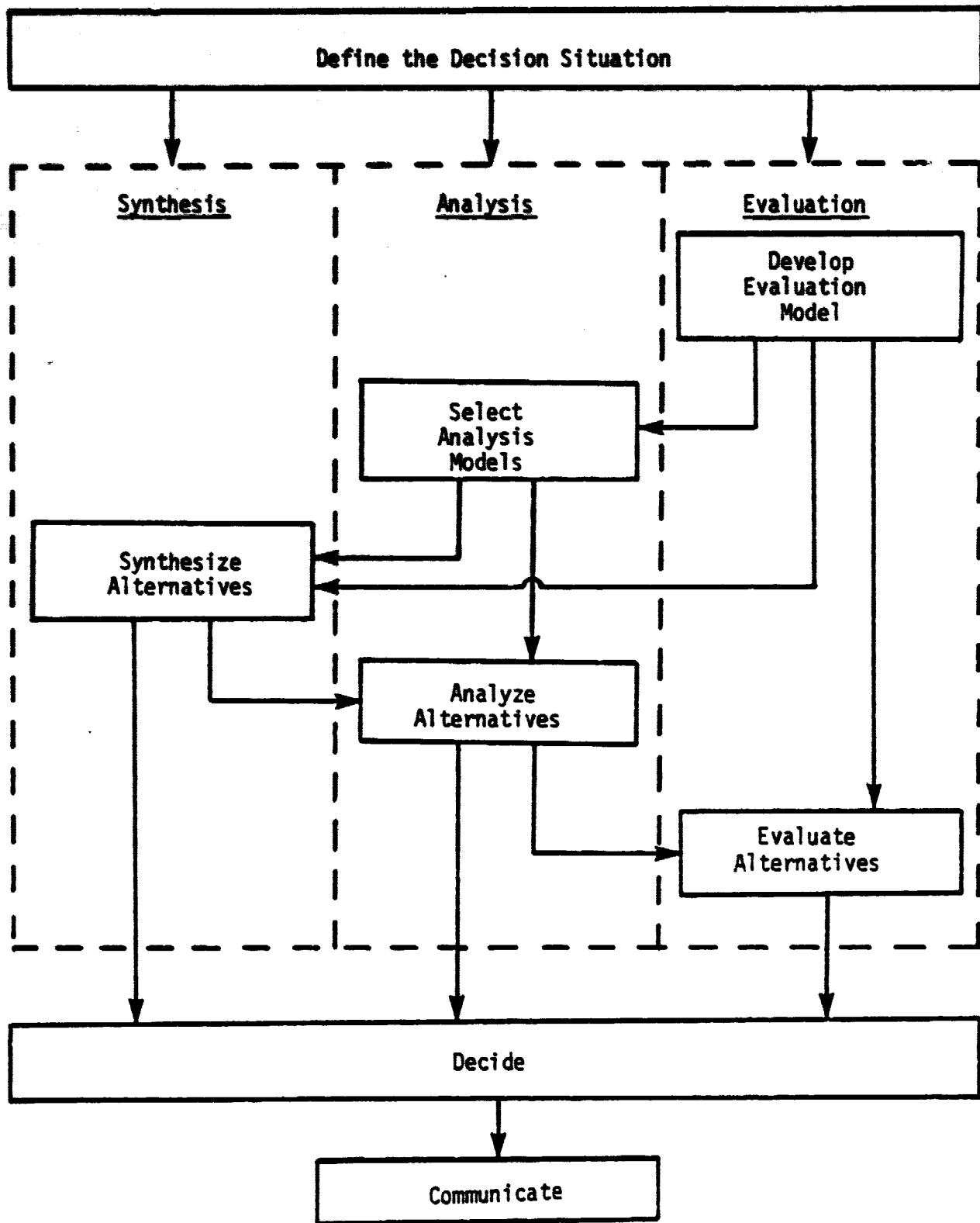


Figure 2 - The Decision-Oriented Problem Solving Process  
(The Decision Process)

presents a sequence of activities designed to provide maximum guidance for determine the five options above.

## 2.4 The Evaluation Model

Management requirements for decision-oriented evaluation imply not only that physical and socio-economic systems be modeled for *analysis* (the estimation of outcomes) but also that the appropriate *value system* be modeled for purposes of communication, consistency, and compatibility. Furthermore, having a model of the value system to be used in evaluating alternatives explicitly defines the outputs required of analysis and, hence, guides the identification of models to provide such outputs.

The evaluation model should:

- Identify and define the *decision criteria*, the specific quantifiable variables suitable for comparison of alternative inter-city passenger-freight transportation systems.
- Display how the decision criteria are derived from and relate to those general and conceptual measures of a transportation system and service which will appropriately portray the overall economic and technical characteristics of any transportation system.
- Present quantitative weighting relationships to be used in transforming estimates of consequences, measured in physical or economic units, into relative worth.
- Combine weighting relationships of the individual criteria into an objective function for computing the relative worth of each transportation alternative. The objective function will provide the uniform means of comparing the attributes of the different modal systems.



## 2.5 Hierarchy of Values

Available theory does not provide explicit guidance for selection of an appropriate set of decision criteria. There is no generally-accepted objective, automatically-applicable procedure for identifying a set of criteria which contain all significant criteria that are relevant to the decision to be made. *The formulation of the set of criteria is primarily judgmental.*

The technique established as the most useful approach to guiding judgment in identification of a set of criteria is the *hierarchy of values* or relevance tree. The usefulness of this technique derives from the observation that goals and objectives can be analyzed to define general factors influencing their achievement. The ECONERGY basic hierarchy is shown in Figure 3.

### 2.5.1 Transportation Effects

The transportation impacts of an example alternative case are measured under *Transportation Effects (1)* by three categories of criteria: *Intercity Transportation Effectiveness (1.1)*, *Costs (1.2)*, and *Urban Facilities (1.3)*. The effectiveness in achieving the primary mission of a transportation system -- to transport people and goods -- is measured by two comparison criteria: *Passengers (1.1.1)* and *Freight (1.1.2)*. Both Passengers and Freight, in the illustrative example, are defined to include people and goods, respectively, carried by the intercity system (Figure 4).

The flow of funds into and out of the intercity transportation system is measured under *Costs (1.2)* by three criteria: *Investment (1.2.1)*, *Operating Costs (1.2.2)*, and *Operating Surplus/Subsidy (1.2.3)*. Investment and Operating Costs are the estimated necessary flows of dollars into the transportation system. Operating Surplus depends on fare structure and ridership and may be either an additional dollar flow into the transportation system, subsidy, or a return from the system,

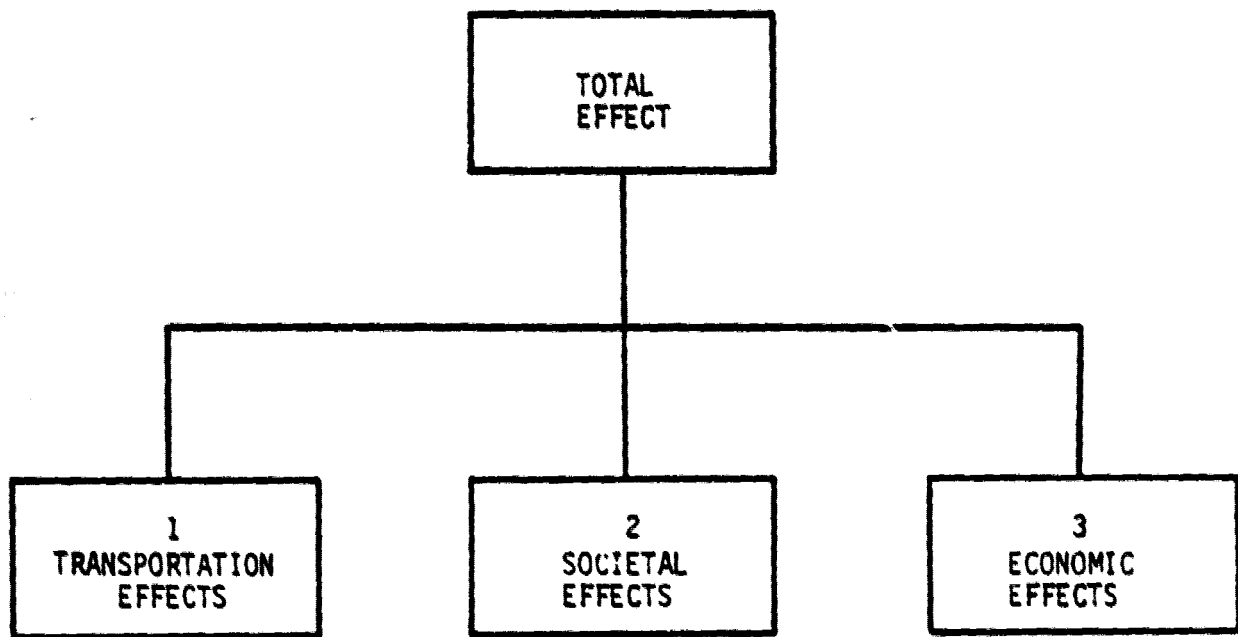


Figure 3 - Hierarchy of Values (Top Level)

**1  
TRANSPORTATION  
EFFECTS**

**1.1  
INTERCITY  
TRANSPORTATION  
EFFECTIVENESS**

**1.1.1  
PASSENGERS**

**1.1.1.1  
AGED**

**1.1.1.2  
POOR**

**1.1.1.3  
DISABLED**

**1.1.2  
FREIGHT**

**1.1.2.1  
AGRICULTURAL  
PRODUCTS**

**1.1.2.2  
FOSSIL FUELS**

-----

-----

**1.2  
COSTS**

**1.2.1  
INVESTMENT**

**1.2.2  
OPERATING  
COSTS**

**1.2.3  
OPERATING  
SURPLUS/SUBSIDY**

**1.3  
URBAN  
FACILITIES**

**1.3.1  
AIRPORTS**

**1.3.2  
RAILROAD  
STATIONS**

**1.3.3  
BUS  
STATIONS**

**1.3.4  
ROADWAYS**

through Operating Surplus, of some or all of the Investment and Operating Costs.

The urban interface between the intercity transportation system and other transportation systems is represented by *Urban Facilities* (1.3). Both under-utilization of and excessive demands on urban facilities are represented by *Airports* (1.3.1), *Railroad Stations* (1.3.2), *Bus Stations* (1.3.3) and *Roadways* (1.3.4).

## 2.5.2 Societal Effects

*Societal Effects* (2) are measured by effects on *Human Resources* (2.1) and on *Physical Resources* (2.2). *Human Resources* (2.1) are measured by the distribution of people, *Demography* (2.1.1), and by their *Health Status* (2.1.2). Demography could be partitioned into population densities of various geographical areas within the defined region and households displaced. For purposes of the illustrative example, however, Demography is represented by a population density criterion that measures population shifts into or out of the urban centers. The health impacts of environmental pollution, accidents, and criminal acts could be evaluated separately. Also, various health indices are available for measuring health status (e.g., Berg, 1973; Fanshel and Bush, 1970). For the illustrative example, however, the health effects of environmental pollution, accidents and criminal acts are all included under *Health Status* (2.1.2), and impact on health status *per se* is measured by "injuries", which includes all degradation to health, including death.

Impacts on *Physical Resources* (2.2) could be measured by a large number of criteria, depending on the location of the intercity system and the concerns of the decision-makers. The entire gamut of factors to be considered in Environmental Impact Statements is properly included in this segment of the hierarchy. For purposes of the illustrative example, the effects on *Physical Resources* are represented by *Land Use* (2.2.1), *Property Damage* (2.2.2), *Noise Levels* (2.2.3), and *Visibility* (2.2.4). It is to be emphasized that environmental impact is measured through

mission *effectiveness* criteria such as operating noise levels and pollution levels. The effectiveness criteria are environmental attributes and include contributions of non-transportation sources of, for instance, noise and pollution. The *performance* criteria with respect to noise and air pollution emissions would be the characteristics for use as design requirements during engineering development of the transportation hardware. (Figure 5).

### 2.5.3 Economic Effects

The impacts of an intercity transportation alternative on the regional economy are measured under *Economic Effects* (3) by effects on people, *Human Resources* (3.1); and on the economic system, *Business and Commerce* (3.3). The effect on *Human Resources* is measured by *Employment* (3.1.1). *Physical Resources* (2.2) is represented by *Fossil Fuels* (3.2.1) to reflect current priorities. *Business and Commerce* (3.3) is measured by two comparison criteria: *Gross Regional Product* (3.3.1) and *Interregional Product* (3.3.2). (Figure 6).

## 2.6 Comparison Criteria

The set of criteria defined for the evaluation of intercity transportation modal concepts is mission-oriented; achieving desired levels of the criteria is the mission of the intercity transportation system (Table 1). The criteria are measured in the environments in which the intercity transportation system is embedded and, hence, are applicable to any modal concept. Furthermore, the set of criteria:

- Provides, together with the case description, an unambiguous description of the mission of the intercity transportation system.
- Identifies the attributes by which advantages and deficiencies of various alternative concepts are measured and made visible.

Concurrence of agency management in the set of criteria is, therefore,

mission *effectiveness* criteria such as operating noise levels and pollution levels. The effectiveness criteria are environmental attributes and include contributions of non-transportation sources of, for instance, noise and pollution. The *performance* criteria with respect to noise and air pollution emissions would be the characteristics for use as design requirements during engineering development of the transportation hardware. (Figure 5).

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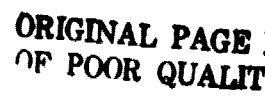
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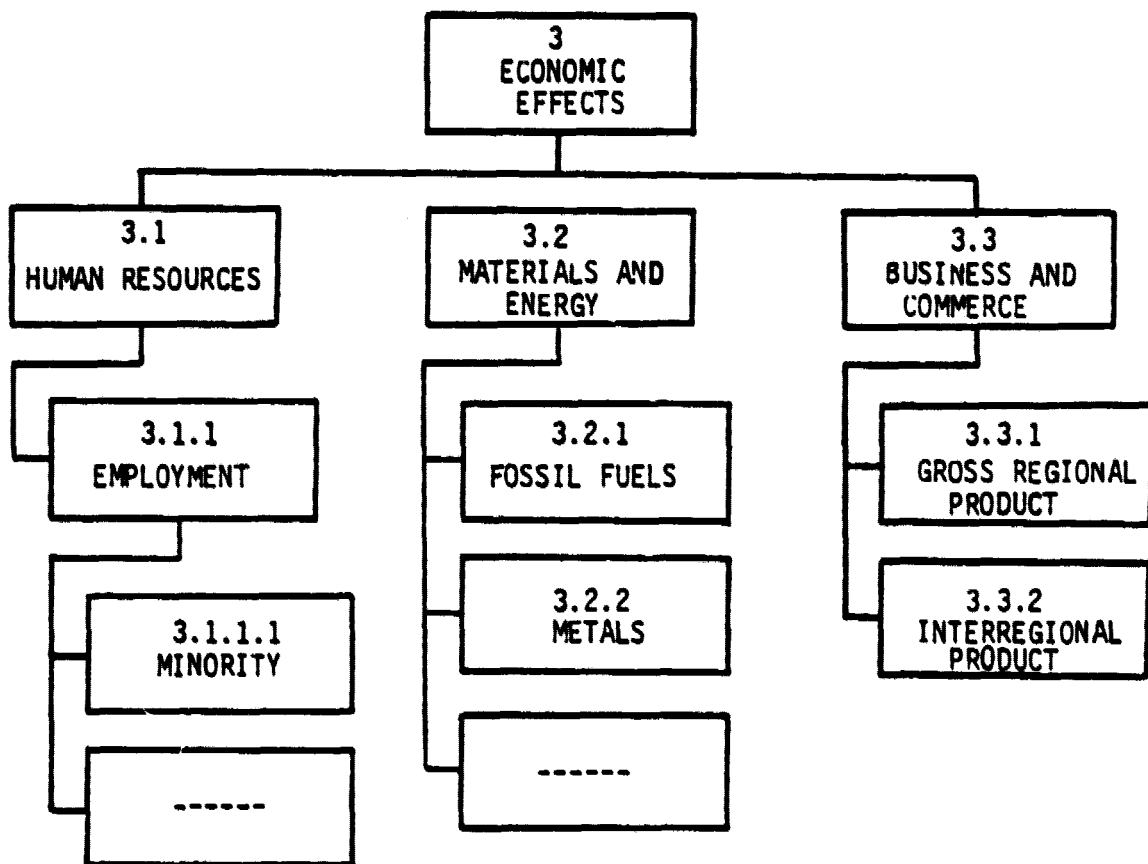


Figure 6 - Hierarchy of Values (Economic Effects)



| 1.<br>Transportation Effects                                                                                                                                                                               | 2.<br>Societal Effects                                                                                                       | 3.<br>Economic Effects                                                                                      |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|
| 1.1.1 Passengers<br>1.1.2 Freight<br>1.2.1 Investment<br>1.2.2 Operating Costs<br>1.2.3 Operating Surplus/<br>Subsidy<br>1.3.1 Airports<br>1.3.2 Railroad Stations<br>1.3.3 Bus Stations<br>1.3.4 Roadways | 2.1.1 Demography<br>2.1.2 Health Status<br>2.2.1 Land Use<br>2.2.2 Property Damage<br>2.2.3 Noise Levels<br>2.2.4 Visibility | 3.1.1 Employment<br>3.2.1 Fossil Fuels<br>3.3.1 Gross Regional<br>Product<br>3.3.2 Interregional<br>Product |

Table 1 - Comparison Criteria (Illustrative Example)

a key element in the application of the methodology.

Example definitions of the comparison criteria are shown in Tables 2a and 2b.

| CRITERION NAME                    | UNIT OF MEASUREMENT<br>FOR NUMERATOR AND<br>DENOMINATOR | DEFINITIONS                                                                                                                                                                                                                                                                     |
|-----------------------------------|---------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Y <sub>1.1.1</sub> Passengers (%) | $\frac{\text{Passenger-Kilometers}}{\text{Year}}$       | $Y_{1.1.1} = 100 \frac{Y_{N 1.1.1}}{Y_{D 1.1.1}}$ <p>Y<sub>N 1.1.1</sub> = Ridership on intercity system</p> <p>Y<sub>D 1.1.1</sub> = Ridership that represents neutral achievement of ridership goals</p>                                                                      |
| Y <sub>1.1.2</sub> Freight (%)    | $\frac{\text{Tonne-Kilometers}}{\text{Year}}$           | $Y_{1.1.2} = 100 \frac{Y_{N 1.1.2}}{Y_{D 1.1.2}}$ <p>Y<sub>N 1.1.2</sub> = Number of tonne-kilometers of freight expected to be carried on intercity system</p> <p>Y<sub>D 1.1.2</sub> = Number of tonne-kilometers of freight that represents neutral achievement of goals</p> |

Table 2a - Definition of Comparison Criteria (Part 1)

| CRITERION NAME                          | UNIT OF MEASUREMENT<br>FOR NUMERATOR AND<br>DENOMINATOR | DEFINITIONS                                                                                                                                                                                                                                                                                                        |
|-----------------------------------------|---------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1.2.3 Operating Surplus/<br>Subsidy (%) | Dollars/Year                                            | $Y_{1.2.3} = 100 \frac{\text{Usercharges} - Y_{N 1.2.2}}{Y_{N 1.2.2}}$ $Y_{D 1.2.3} = Y_{N 1.2.2}$ <p>When <math>Y_{1.2.3} &gt; 0</math>, <math>Y_{1.2.3}</math> <math>\Delta</math> Operating Surplus</p> <p>When <math>Y_{1.2.3} &lt; 0</math>, <math>Y_{1.2.3}</math> <math>\Delta</math> Operating Subsidy</p> |
| 1.3.1 Airports (%)                      | Flights/Day                                             | $Y_{1.3.1} = 100 \frac{Y_{N 1.3.1}}{Y_{D 1.3.1}}$ $= 100 \frac{\text{Number of flights/day}}{\text{Airport design capacity}}$                                                                                                                                                                                      |
| 1.3.2 Railroad Stations (%)             | Trains/Day                                              | $Y_{1.3.2} = 100 \frac{Y_{N 1.3.2}}{Y_{D 1.3.2}}$ $= 100 \frac{\text{Number of trains/day}}{\text{Station design capacity}}$                                                                                                                                                                                       |

Table 2b - Definition of Comparison Criteria (Part 2)

### 3. THE EVALUATION FRAMEWORK

#### 3.1 Relative Worth

The worth of each comparison criterion must be scaled with reference to Figure 7, showing three characteristic relative worth functions:

1. Specify Range of Interest. For each criterion, lower and upper limits of the range of interest are specified. These limits are based on an understanding of the particular case description under consideration. The range of interest is broad enough to include all anticipated consequences for any of the modal alternatives. To permit evaluation of achievement and non-achievement of transportation objectives, the range of interest includes both desirable and undesirable magnitudes of each criterion.
2. Identify Threshold. Since the range of interest specified in 1 includes both desirable and undesirable quantities of a criterion, it must also include a neutral contribution to success or failure. This neutral point, or *threshold*, is indicated by  $Y_T$ .

The importance of specifying the threshold of each criterion lies in the fact that *all thresholds, regardless of criterion, represent the same relative worth -- neutral desirability or neutral contribution to success or failure --* and may, therefore, be assigned the same relative worth number. A relative worth of zero is assigned to each  $Y_T$  so that positive relative worth represents a desirable outcome.

3. Define Relative Worth Functions. The evaluation methodology utilizes a cardinal scale for measuring relative worth. Defining a cardinal scale of measurement requires arbitrarily anchoring *two and only two*, points on the scale to designated phenomena or quantities.

*Any of a number of techniques may be used to elicit the judgmental data*

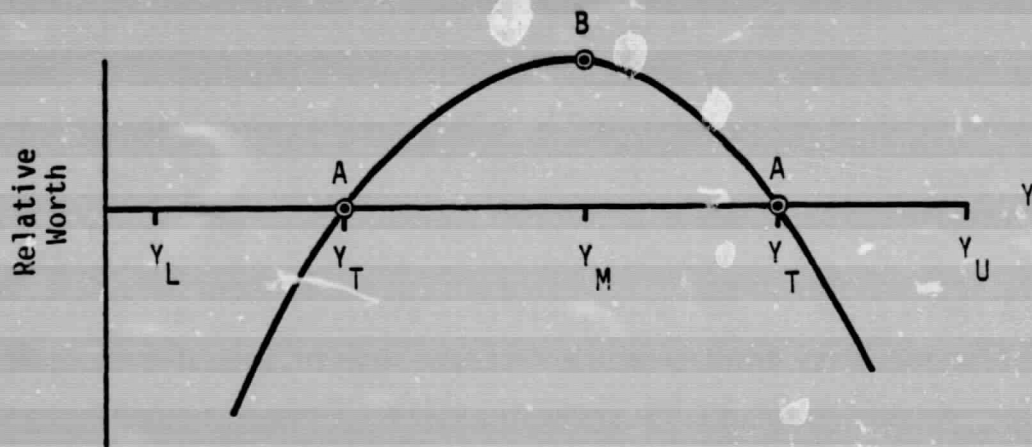
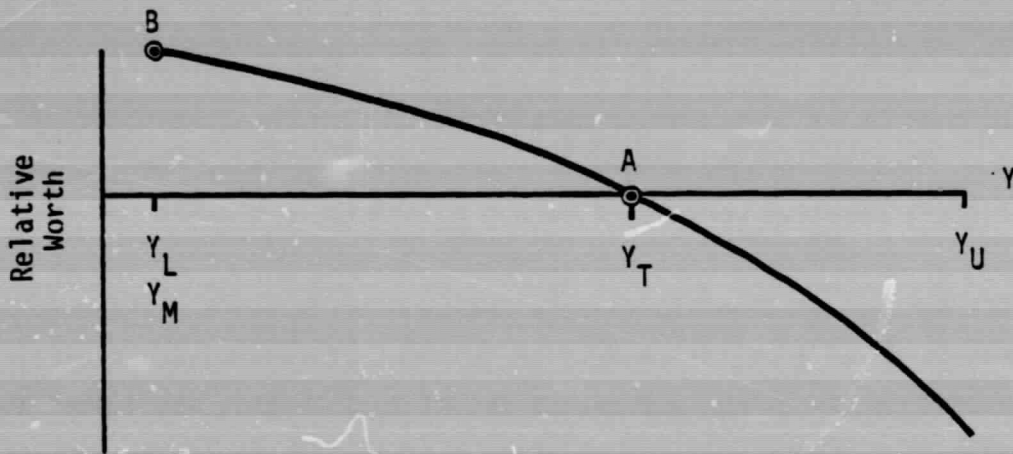
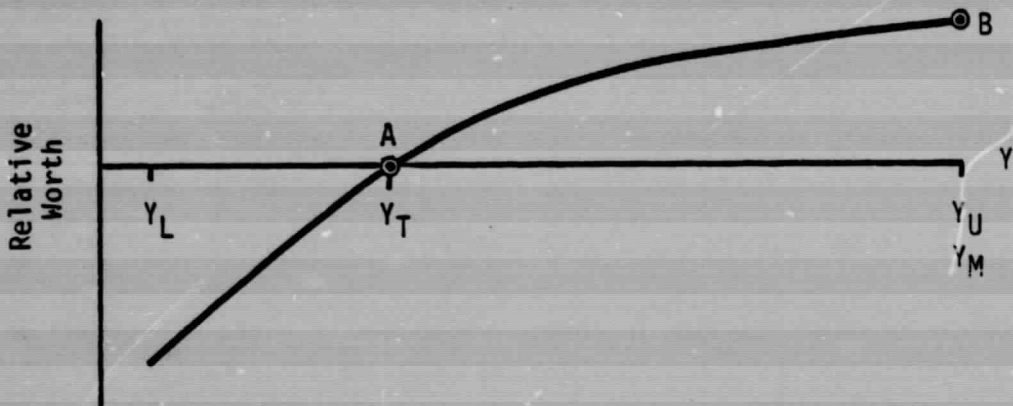


Figure 7 - Illustrative Relative Worth Functions

*needed to identify the relative worth function.*

*Whatever the technique, knowledgeable personnel willing to respond to questions concerning tradeoffs of various amounts of a criterion are key to defining a relative worth function. Knowledge and understanding of intercity transportation policies and objectives are necessary to assure that the relative worth functions comprise an appropriate model of the value system to be used in a particular decision situation.*

Figure 8 shows how the procedure might work for the illustrative example.

### 3.2 Relative Weights

The relative worth functions are scaled so that, for all criteria, a relative worth of zero means neutral contribution to achievement of objectives. One point in common, however, is not sufficient to assure a common scaling for all relative worths. A second relationship between criteria is needed.

The second relationship is obtained by considering  $Y_M$ , the most preferred magnitude of a criterion  $Y$ . The judgment of knowledgeable personnel is needed to assign numbers to the set of  $Y_M$  such that the number assigned to each  $Y_M$  represents its relative contribution to achievement of objectives. The numbers so assigned are the relative weights, (see Figure 9).

The relative worths obtained from the relative worth functions are transformed to a common scaling by multiplying by the respective relative weights.

A score equal to the relative weights shown on the chart implies a perfect intercity transportation system -- one that results in  $Y_M$  for all criteria over the entire planning period. Obviously, no actual system is perfect; tradeoffs among the criteria and imperfections in real systems result in overall scores of less than 100.

The relative worths obtained for alternatives evaluated are placed in

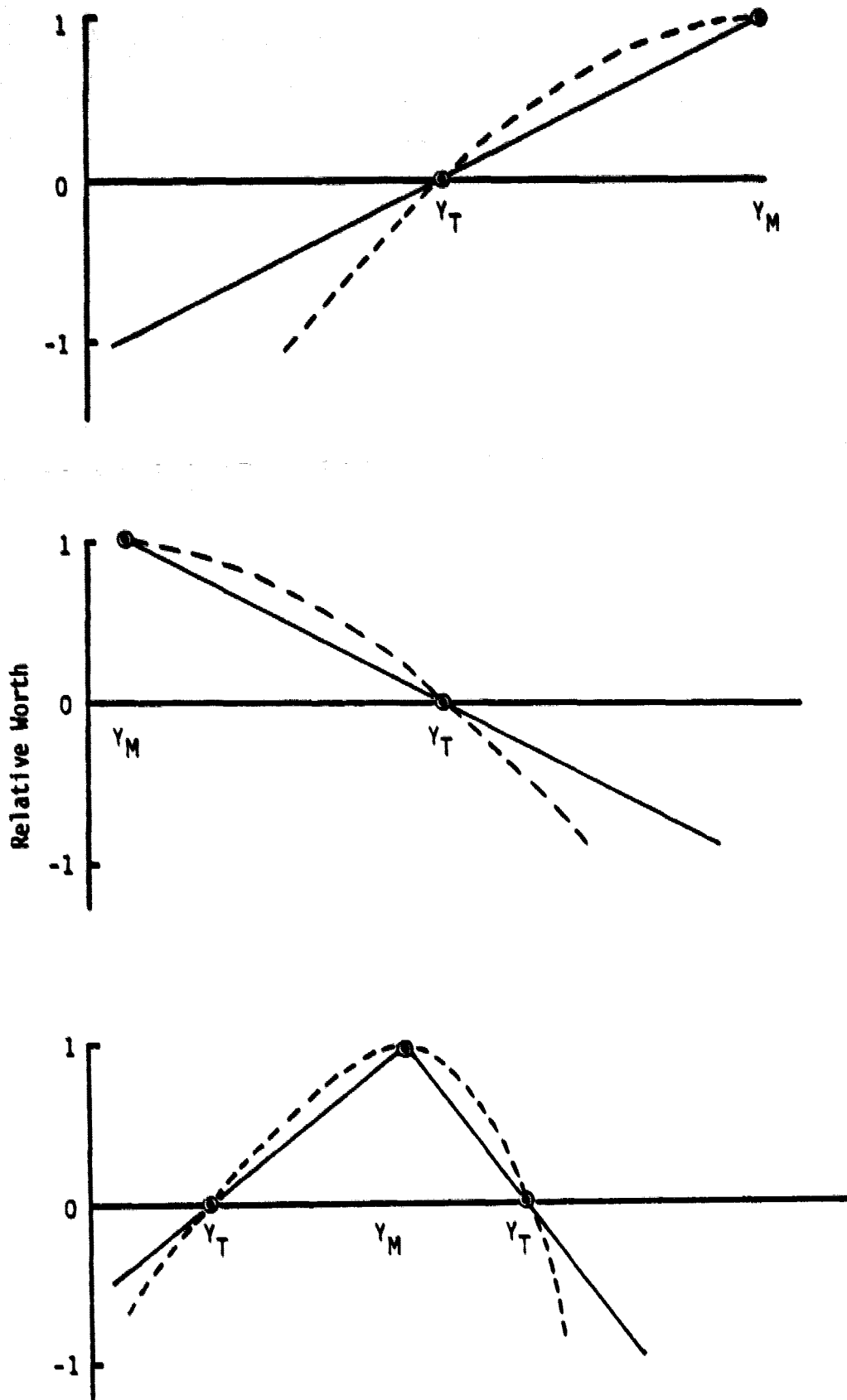


Figure 8 - General Form of Linearized Relative Worth Functions



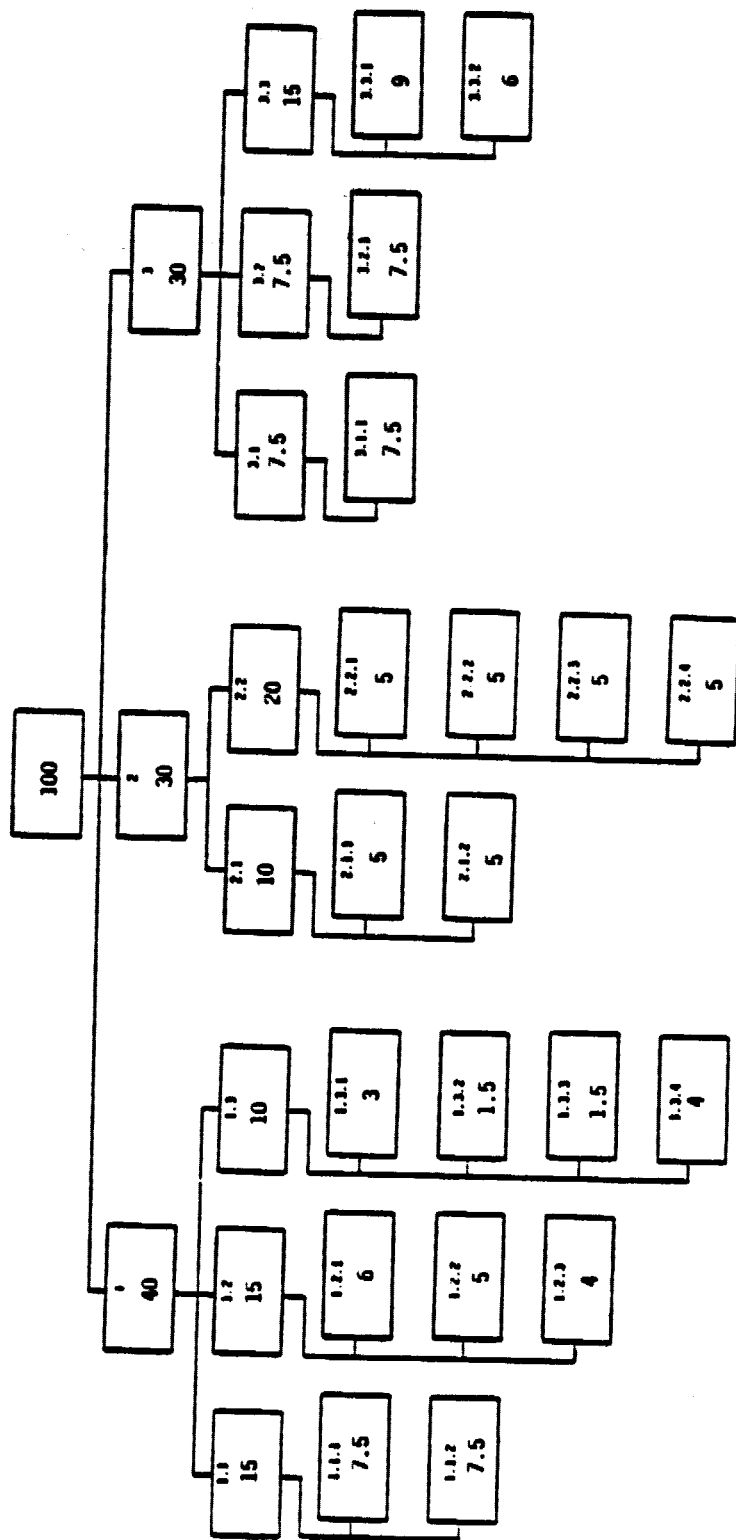


Figure 9 - Relative Weights

perspective by considering that 100 is the score for perfection and zero is the score for neutral achievement of objectives. A negative score indicates an alternative that is, with all tradeoffs considered, an unsatisfactory solution to the transportation problem being studied.

### 3.3 The Discount Function

The methodology incorporates the following three improvements over standard discounting practice:

1. A non-standard discount function may be used. Discounting transforms prospective relative worths for the various criteria, as values over time, to equivalent relative worths in the present; it accounts for relative worth of the time dimension.
2. Provision is made to discount different value elements differently. Agency transportation policies and objectives may require, for example, that lives saved or numbers of people employed in the year 2000 be discounted to the present differently from the way in which investment or operating costs are discounted.
3. The discount function is applied to the time flow of *relative worth rather than to the time flow of dollars, or passengers, or freight, etc.* In conventional economic evaluation of investment alternatives, projected alternative time flows of dollars (criterion variable) are converted to equivalent present worths and then the investor factors this value by his own subjective judgement of the relative worth of that present value. The problem with this conventional approach is that cash flows representing financial disaster in some future year may be masked by the present worth conversion. If the time flow of dollars is converted to relative worth representing the *impact* of the flow of dollars in each year, then the present worth computation can more accurately measure relative contribution of flow over time to achievement of objectives.

## 4. CASE DESCRIPTION - ILLUSTRATIVE EXAMPLE

### 4.1 Alternatives

#### ● PORTFOLIOS

An important feature of the ECONERGY methodology is the way in which alternative systems are defined. A new technology, for example TACV, should not be evaluated only by comparison with what it might eventually replace because if such new technology should prove viable, it will change the composition of all modes making up the transportation system. Therefore, the alternatives are *portfolios* of modal systems which meet the aspirations to a greater or lesser degree.

#### ● NEW TECHNOLOGIES

The new technologies to be considered are:

- tracked air cushion vehicle (TACV) - a high speed fixed guideway system
- improved passenger train (IMPT) - an advanced railroad train capable of 240 km/hr (150 mi/hr)
- improved conventional takeoff or landing aircraft (CTOL) - the next generation of commercial aircraft.

### 4.2 Aspirations

Relative worths are non-dimensionalized by dividing by measures unrelated to the specific technologies comprising the system alternative. Appropriately, the denominators in the relative worth ratio should be associated with the long term *aspiration* for improved transportation. Such aspiration must be determined by examination of feasible long-term economic and social projections of population, GNP, urbanization, etc. These projections, representing aspired-to-levels, should be optimistic but realizable. Within such a long-term socio-economic environment, the kind of

transportation system aspired-to can then be specified in terms of numbers of passengers to be carried, levels of pollution to be achieved, etc., (i.e.  $\bar{Y}$  variables).

Having established the aspiration of the long-term future and knowing how past trends have developed transportation up to the present, transportation developments needed to achieve the aspiration are then readily determined and specified by the criteria.

The transportation aspiration is unrelated to any particular means designed to achieve it. The aspiration is *alternative-independent* (i.e., independent of mode or technology which may be needed to achieve the aspiration).

#### 4.3 Consequences

There may be a number of designs for achieving the aspiration. These designs, including varying combinations of modes and technological levels, will all have different levels of criteria-satisfaction. For each design, constituting an alternative, the actual criteria levels ( $\bar{Y}$ ) are determined. These values are the numerators in the abscissas of relative worth functions.

The numerators, being the actual measure of the degree to which the aspiration in each variable is met, are *alternative-dependent*.

## 5. EVALUATION

The evaluation of the results of the example case led to a balanced weighting of five alternatives, see Figure 10, Evaluation Results.

### 5.1 Sensitivity to Relative Worth Functions

Choice of alternative may be sensitive to shape of relative worth functions. In the example case, no change in ordering was indicated by linearizing the relative worth function, although it did indicate a shift in importance between *Societal Effects* and *Transportation Effects*, TACV versus IPT, Table 3.

### 5.2 Sensitivity to Relative Weights

The sensitivity to relative weights were demonstrated by taking two viewpoints. These were based on an economic growth value approach and a more conservative viewpoint of a hypothetical environmentalist, Figure 11.

### 5.3 Evaluation of R&D

When a new technology is introduced as a component of a transportation system, the comparison of the alternatives includes the timing of the introduction of the technology. The eventual success of the technology and the best time for introducing it into the system will depend on the scheduling and funding of R&D programs, as well as on the types of such R&D programs. Thus, the application of the ECONERGY methodology, by revealing the weighted aggregate relative worths of all the alternatives being considered with their related R&D requirements, establishes the scheduling and funding requirements for R&D.

The sensitivity to R&D programs is readily shown by computing relative worths of alternatives which are identical except for the schedule and funding of R&D, Figure 12.

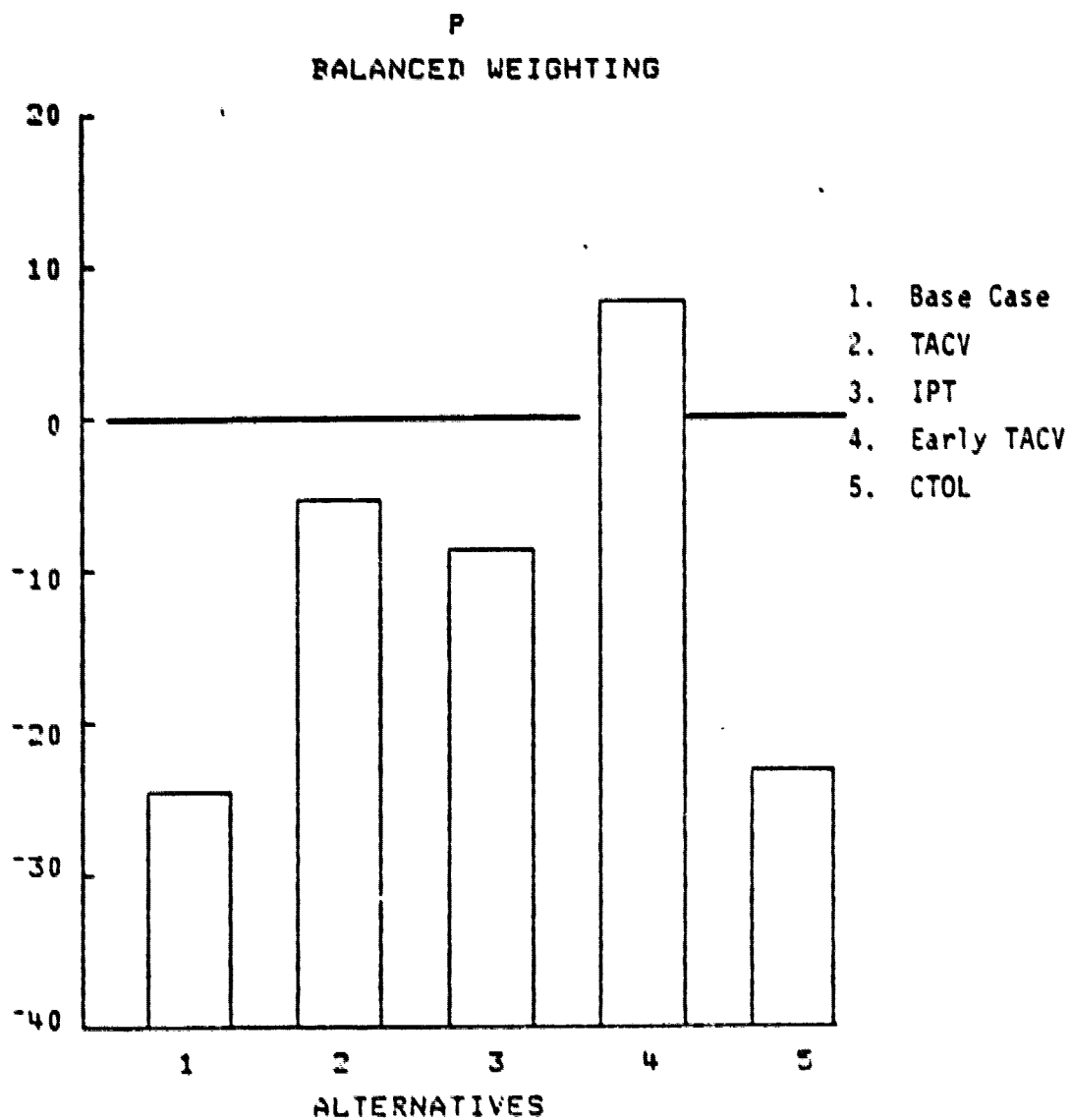


Figure 10 - Total Relative Worth: Baseline Data

|                        | Baseline Data |      | Linear Relative Worth |      |
|------------------------|---------------|------|-----------------------|------|
|                        | U             | Rank | U                     | Rank |
| <b><u>BASECASE</u></b> |               |      |                       |      |
| P <sub>1</sub>         | - 4.15        | 4    | - .33                 | 4    |
| P <sub>2</sub>         | -16.51        | 4    | -5.16                 | 4    |
| P <sub>3</sub>         | - 3.83        | 4    | - .79                 | 4    |
| P                      | -24.48        | 4    | -6.28                 | 4    |
| <b><u>TACV</u></b>     |               |      |                       |      |
| P <sub>1</sub>         | - 2.33        | 1    | .36                   | 2    |
| P <sub>2</sub>         | - 2.25        | 2    | 1.05                  | 1    |
| P <sub>3</sub>         | - .63         | 1    | .30                   | 1    |
| P                      | - 5.22        | 1    | 1.72                  | 1    |
| <b><u>IPT</u></b>      |               |      |                       |      |
| P <sub>1</sub>         | - 3.56        | 2    | .13                   | 1    |
| P <sub>2</sub>         | - 1.83        | 1    | .18                   | 2    |
| P <sub>3</sub>         | - 3.17        | 2    | - .64                 | 2    |
| P                      | - 8.57        | 2    | - .34                 | 2    |
| <b><u>CTOL</u></b>     |               |      |                       |      |
| P <sub>1</sub>         | - 3.91        | 3    | - .29                 | 3    |
| P <sub>2</sub>         | -15.41        | 3    | -4.92                 | 3    |
| P <sub>3</sub>         | - 3.74        | 3    | - .78                 | 3    |
| P                      | -23.06        | 3    | -5.99                 | 3    |

Table 3 - Effect of Linearized Relative Worth

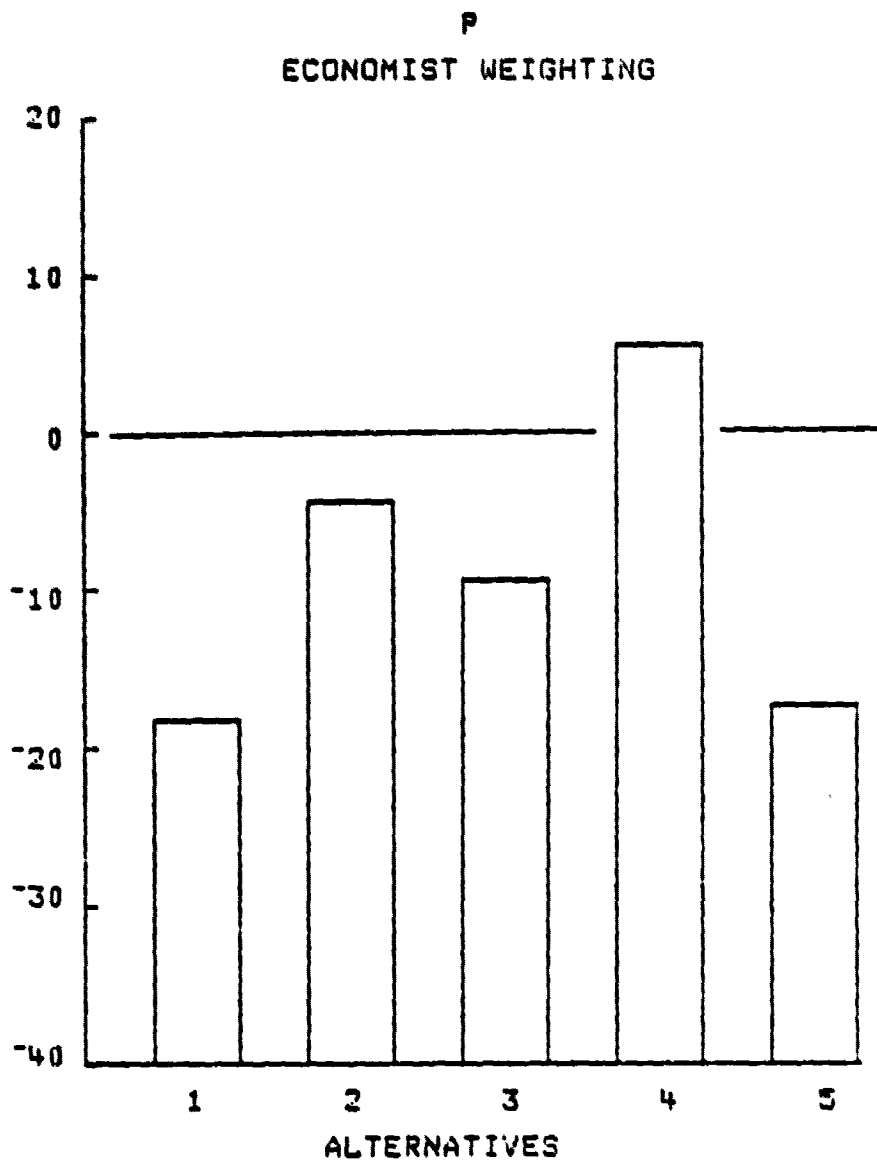


Figure 11a - Total Relative Worth:  
"Economist's" Weights



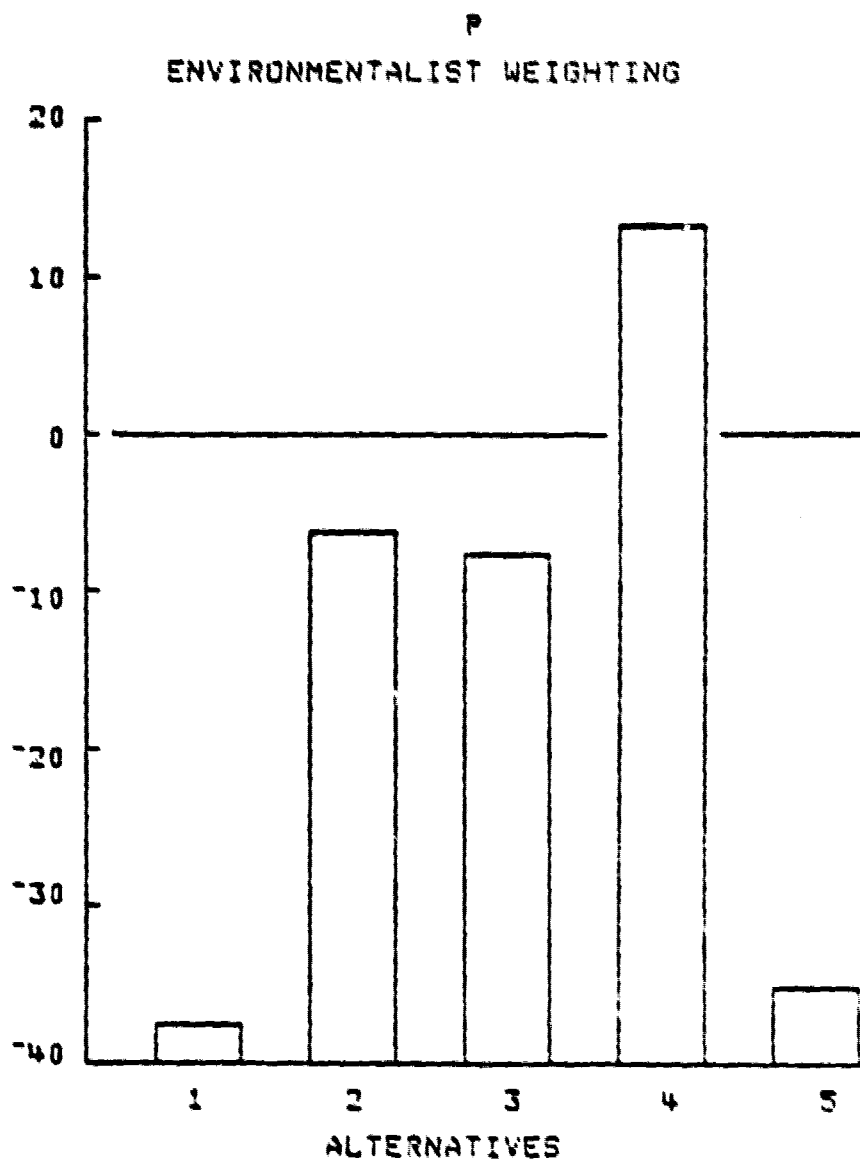


Figure 11b - Total Relative Worths:  
"Environmentalists" Relative Weights

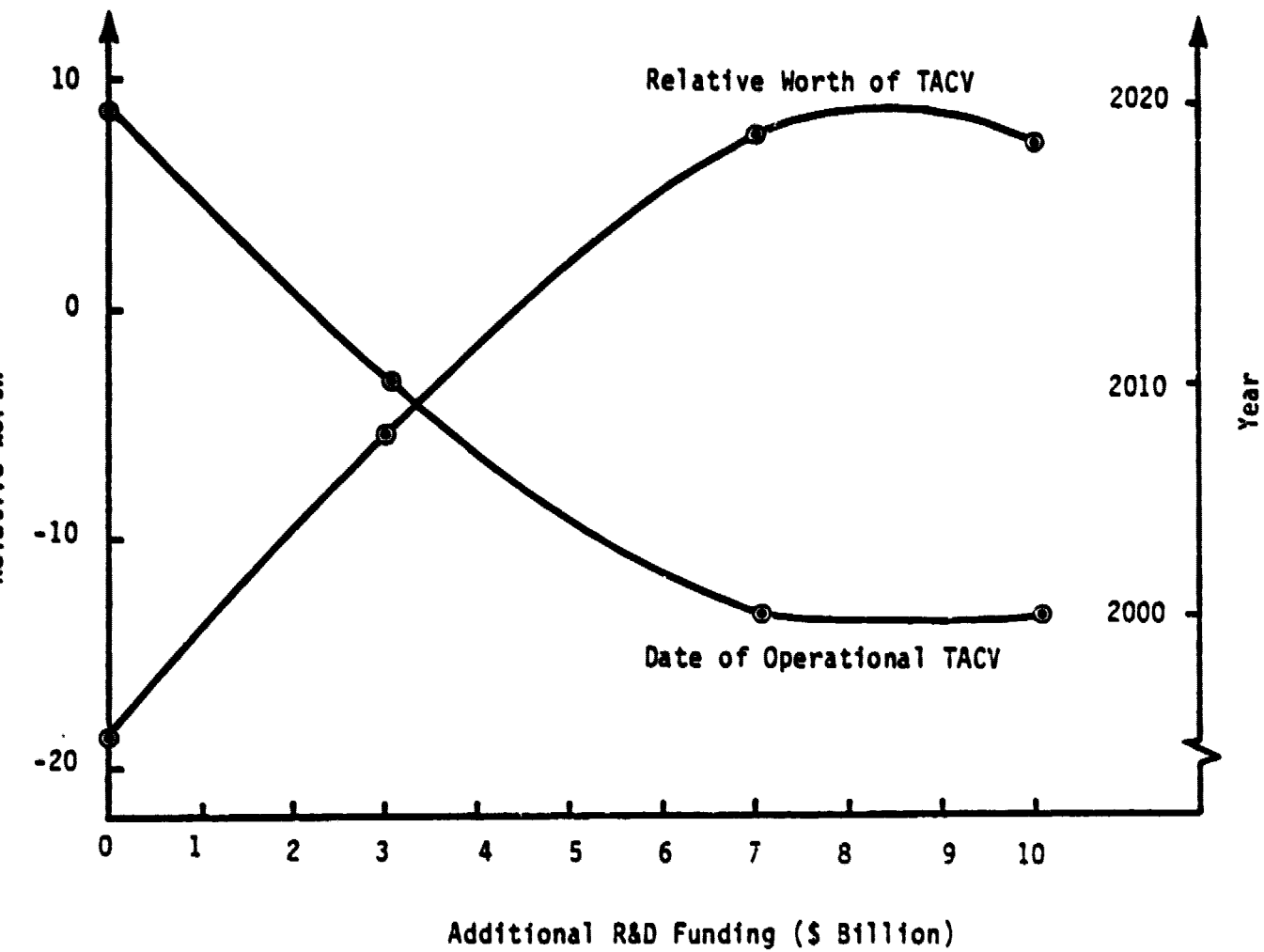


Figure 12 - Effects of Additional R&D Funding

## 6. CONCLUSIONS

A new method for dealing satisfactorily with long-term development of new technology for transportation systems has been introduced. This new method is based on establishing an aspiration for desirable transportation features in a long-run future, compatible with long-term socio-economic projections.

Risk is innate in new technology. However, the risk in any proposed technology should be assessed in the overall context of system risk. The ECONERGY method, by considering alternatives as portfolios of technologies, meets this essential.

Traditional methodologies for comparing transportation systems have been used for specific technologies and for specific regional systems. Comparisons are made in terms of performance measures usually limited in number and with short-term horizons. The ECONERGY methodology provides a means for considering any number of variables, but what is more significant, shifts the focus from performance to worth of performance. By systematic emphasis on concern for those values on which judgmental decisions can best be made and providing an integrating mechanism, a manageable and readily applied technique is provided.

In one way or another, a decision is reached by applying some value system -- always judgmental. The ECONERGY methodology calls for breaking down the problem into bite-sized elements -- the performance variables -- and applying judgments into the transformation to relative worths. The degree to which this subdivision is carried out may improve the results, but this is up to the analyst. The level of effort to accomplish the evaluation can range from modest to extensive, depending on the degree of involvement of expert opinion relative to analytic computation.

The definition of alternative transportation systems includes the kinds of R&D as well as the potential loss for not launching timely R&D programs.

The Executive Office has specified policies governing new systems acquisition and DOT has established long-term National transportation objectives. The ECONERGY Methodology is designed to best meet both requirements.